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FORM PTO-1390 (REV 10-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: P/2778-12

U.S. APPLICATION NO. (If known, see 37 CFR 1.5): 09/913014

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/SG99/00139	8 December 1999	

TITLE OF INVENTION: APPARATUS FOR DETECTING THE OSCILLATION AMPLITUDE OF AN OSCILLATING OBJECT

APPLICANT(S) FOR DO/EO/US: Liming FAN et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371.
3. [X] This is an express request to promptly begin national examination procedures (35 U.S.C. 371(f)).
4. [ ] The US has been elected by the expiration of 19 months from the priority date (PCT Article 31).
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   - a. [ ] is attached hereto (required only if not communicated by the International Bureau).
   - b. [X] has been communicated by the International Bureau.
   - c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [ ] An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
7. [X] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   - a. [ ] are attached hereto (required only if not communicated by the International Bureau).
   - b. [ ] have been communicated by the International Bureau.
   - c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   - d. [X] have not been made and will not be made.
8. [ ] An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. [ ] An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 16 below concern document(s) or information included:

11. [ ] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [X] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [X] A FIRST preliminary amendment.
    [ ] A SECOND or SUBSEQUENT preliminary amendment.
14. [ ] A substitute specification.
15. [ ] A change of power of attorney and/or address letter.
16. [X] Other items or information:
    8 sheets of drawings.
    Print PEFS Form.
    PCT/IB/308 form.

EXPRESS MAIL CERTIFICATE

I hereby certify that this correspondence is being deposited with the United States Postal Service as Express Mail Post Office to Addresses (mail label EL855849345 in an envelope addressed to: Asst. Commissioner for Patents, Washington, D.C. 20231, on August 8, 2001.

Dorothy Jenkins
Name of Person Mailing Correspondence

Dorothy Jenkins
Signature

August 8, 2001
Date of Signature

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U.S. APPLICATION NO (if known, see 37 CFR 1.5) 09/913014	INTERNATIONAL APPLICATION NO PCT/SG99/00139	ATTORNEY'S DOCKET NUMBER P/2778-12

17. [X] The following fees are submitted:

	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):		
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1000.00**		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO **$860.00**		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$710.00**		
International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$690.00**		
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 710.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	18 - 20 =	0	X $18.00	$	
Independent claims	2 - 3 =	0	X $80.00	$	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)		0	+ $270.00	$	

TOTAL OF ABOVE CALCULATIONS =	$ 710.00	
[ ] Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.	$	
SUBTOTAL =	$ 710.00	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +	$	
TOTAL NATIONAL FEE =	$ 710.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +	$ 40.00	
TOTAL FEES ENCLOSED =	$ 750.00	
	Amount to be refunded:	$
	charged:	$

a. [X] A check in the amount of $ 750. to cover the above fees is enclosed. **Check No.** 5919

b. [ ] Please charge my Deposit Account No. ______ in the amount of $______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 15-0700. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

OSTROLENK, FABER, GERB & SOFFEN, LLP
1180 Avenue of the Americas
New York, NY 10036-8403

Tel: (212) 382 0700

Robert C Faber
SIGNATURE

Robert C. Faber
NAME

24,322
REGISTRATION NUMBER

INVENTOR INFORMATION

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09/913014

Inventor One Given Name:: Liming
Family Name:: Fan
Postal Address Line One:: Blk 263 Yishun Street 22 #11-177
City:: Singapore
Country:: Singapore
Postal or Zip Code:: 760263
Citizenship Country:: China
Inventor Two Given Name:: Hon Yu, Peter
Family Name:: NG
Postal Address Line One:: 985 Bukit Timah Road #05-09
City:: Singapore
Country:: Singapore
Postal or Zip Code:: 589627
Citizenship Country:: Singapore
Inventor Three Given Name:: Xianbin
Family Name:: Zhu
Postal Address Line One:: Blk 724 Yishun St 71 #10-181
City:: Singapore
Country:: Singapore
Postal or Zip Code:: 760724
Citizenship Country:: China
Inventor Four Given Name:: Yam Mo
Family Name:: Wong
Postal Address Line One:: 255 Tagore Avenue #11-02
City:: Singapore
Country:: Singapore
Postal or Zip Code:: 787796
Citizenship Country:: Singapore
Inventor Five Given Name:: Keng Yew
Family Name:: Song
Postal Address Line One:: Blk 420 Serangoon Central #08-406
City:: Singapore
Country:: Singapore
Postal or Zip Code:: 550420
Citizenship Country:: Singapore

CORRESPONDENCE INFORMATION

Correspondence Customer Number:: 000002352
Electronic Mail One:: email@ostrolenk.com

APPLICATION INFORMATION

Title Line One:: APPARATUS FOR DETECTING THE OSCILLATION
Title Line Two:: AMPLITUDE OF AN OSCILLATING OBJECT
Total Drawing Sheets:: 8
Formal Drawings?:: Yes

Application Type:: Utility
Docket Number:: P/2778-12
Secrecy Order in Parent Appl.?:: No

CONTINUITY INFORMATION

This application is a:: 371 OF
> Application One:: PCT/SG99/00139
Filing Date:: 12-08-1999

Source:: PrintEFS Version 1.0.1

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P/2778-12

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of

Liming FAN et al | Date: August 8, 2001

Serial No.: | Group Art Unit:

Filed: | Examiner:

For: APPARATUS FOR DETECTING THE OSCILLATION AMPLITUDE OF AN OSCILLATING OBJECT

Asst. Commissioner for Patents
Washington, D.C. 20231

AMENDMENT/SUBMISSION

Prior to examination, please amend the application as follows.

FEE CALCULATION

Any additional fee required has been calculated as follows:

_____ If checked, "Small Entity" status is claimed.

	NO. CLAIMS AFTER AMENDMENT		HIGHEST NO. PREVIOUSLY PAID FOR		EXTRA PRESENT		RATE	ADDIT. FEE
TOTAL	18	MINUS	20	* =	0	X	($9 SE or $18)	$
INDEP.	2	MINUS	3	** =	0	X	($40 SE or $80)	$
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM						X	($135 SE or $270)	$ ------
* not less than 20** not less than 3							TOTAL	$

If any additional payment is required, a check which includes the calculated fee of $____ (OFGS Check No. ______) is attached.

In the event the actual fee is greater than the payment submitted or is inadvertently not enclosed or if any additional fee during the prosecution of this application is not paid, the Patent Office is authorized to charge the underpayment to Deposit Account No. 15-0700.

CONTINGENT EXTENSION REQUEST

If this communication is filed after the shortened statutory time period had elapsed and no separate Petition is enclosed, the Commissioner of Patents and Trademarks is petitioned, under 37 C.F.R. § 1.136(a), to extend the time for filing a response to the outstanding Office Action by the number of months which will avoid abandonment under 37 C.F.R. § 1.135. The fee under 37 C.F.R. § 1.17 should be charged to our Deposit Account No. 15-0700.

AMENDMENTS

_X_ If checked, amendment(s) to the specification and/or claims are submitted herewith.

1. ___ If checked, an abstract is submitted as the last page of Appendix A.

2. Specification:

Please delete the paragraph(s)/section(s) beginning at page,
and replace such paragraph(s)/section(s) pursuant to 37 C.F.R. § 1.121(b)(ii) with the "clean" version attached hereto as Appendix A. Entry is respectfully requested. A version with markings to show the changes made pursuant to 37 C.F.R. § 1.121(b)(iii) is attached hereto as Appendix B.

3. Claims:

Please amend claims 5-8, 10-12, 15, 16 and 18 pursuant to 37 C.F.R. § 1.121(c)(i) as set forth in the "clean" version attached hereto as Appendix A. Entry is respectfully requested. A version with markings to show the changes made pursuant to 37 C.F.R. § 1.121(c)(ii) is attached hereto as Appendix B.

___ If checked, the optional complete set of "clean" claims pursuant to 37 C.F.R. § 1.121(c)(3) is attached hereto as Appendix C.

REMARKS/ARGUMENT

This Preliminary Amendment is being submitted to eliminate the improper multiple dependent claims and to reduce the government filing fee.

EXPRESS MAIL CERTIFICATE

I hereby certify that this correspondence is being deposited with the United States Postal Service as Express Mail to Addressee (mail label # EL855849345US) in an envelope addressed to: Asst. Commissioner for Patents, Washington, D.C. 20231, on August 8, 2001:

Dorothy Jenkins
Name of Person Mailing Correspondence

Dorothy Jenkins
Signature

August 8, 2001
Date of Signature

Respectfully submitted,

Robert C. Faber

Robert C. Faber
Registration No.: 24,322
OSTROLENK, FABER, GERB & SOFFEN, LLP
1180 Avenue of the Americas
New York, New York 10036-8403
Telephone: (212) 382-0700

RCF/jc

APPENDIX A

"CLEAN" VERSION OF EACH PARAGRAPH/SECTION/CLAIM
37 C.F.R. § 1.121(b)(ii) AND (c)(i)

CLAIMS (with indication of amended or new):

(Amended) 5. Apparatus according to claim 3, wherein the oscillation amplitude is controlled in real time.

(Amended) 6. Apparatus according to claim 1, wherein the width of each of the first and second optical radiation sensing areas is greater than the sum of half the width of the oscillating object and the amplitude of oscillation of the object.

(Amended) 7. Apparatus according to claim 1, wherein the first and second optical radiation sensing areas are directed towards the optical radiation source.

(Amended) 8. Apparatus according to claim 1, wherein the first and second optical radiation sensing areas are not directed towards the optical radiation source and the detector further comprises an optical device to direct the optical radiation onto the first and second sensing areas.

(Amended) 10. Apparatus according to claim 1, wherein the oscillating object is a tip of an ultrasonic transducer for use in an ultrasonic welding machine.

(Amended) 11. A wire bonder comprising apparatus according to claim 1.

(Amended) 12. A wire bonder according to claim 3, wherein the control device comprises an ultrasonic wave controller.

(Amended) 15. A method according to claim 13, wherein the oscillating object is a tip of an ultrasonic transducer in an ultrasonic welding machine.

(Amended) 16. A method according to claim 13, further comprising controlling the oscillation amplitude of the oscillating object in response to the determined oscillation amplitude.

(Amended) 18. A method according to claim 16, wherein the oscillation amplitude is controlled in real time.

APPENDIX B

VERSION WITH MARKINGS TO SHOW CHANGES MADE

37 C.F.R. § 1.121(b)(iii) AND (c)(ii)

CLAIMS:

5. Apparatus according to claim 3 [or claim 4], wherein the oscillation amplitude is controlled in real time.

6. Apparatus according to [any of claims 1 to 5] claim 1, wherein the width of each of the first and second optical radiation sensing areas is greater than the sum of half the width of the oscillating object and the amplitude of oscillation of the object.

7. Apparatus according to [any of the preceding claims] claim 1, wherein the first and second optical radiation sensing areas are directed towards the optical radiation source.

8. Apparatus according to [any of claims 1 to 6] claim 1, wherein the first and second optical radiation sensing areas are not directed towards the optical radiation source and the detector further comprises an optical device to direct the optical radiation onto the first and second sensing areas.

10. Apparatus according to [any of the preceding claims] claim 1, wherein the oscillating object is a tip of an ultrasonic transducer for use in an ultrasonic welding machine.

11. A wire bonder comprising apparatus according to [any of claims 1 to 9] claim 1.

12. A wire bonder according to claim [11 when dependent on any of claims 3 to 5 or on any of claims 6 to 10 when dependent on any of claims 3 to 5] 3, wherein the control device comprises an ultrasonic wave controller.

15. A method according to claim 13 [or claim 14], wherein the oscillating object is a tip of an ultrasonic transducer in an ultrasonic welding machine.

16. A method according to [any of claims 13 to 15] claim 13, further comprising controlling the oscillation amplitude of the oscillating object in response to the determined oscillation amplitude.

18. A method according to claim 16 [or claim 17], wherein the oscillation amplitude is controlled in real time.

Apparatus for Detecting the Oscillation Amplitude of an Oscillating Object

The invention relates to apparatus for detecting the oscillation amplitude of an oscillating object and in particular, the oscillation amplitude of the capillary tip of an ultrasonic transducer for ultrasonic welding.

During the semiconductor packaging process a semiconductor die (or chip) is bonded to a metal leadframe. This is commonly known as die attachment. Conductive wire is then bonded between electrical contact pads on the die and electrical contacts on the leadframe by a piece of equipment commonly known as a wire bonder. The wire bonder bonds the conductive wire to the die and the leadframe by an ultrasonic welding process, which uses an ultrasonic wave transducer. The ultrasonic wave transducer has a capillary working tip mounted on it and the conductive wire passes through a through bore in the capillary to the capillary tip. It is the tip, which applies the ultrasonic vibration from the transducer to the conductive wire to form the bond. The transducer generates longitudinal vibration of the capillary tip, which bonds the wire onto the die pad or the leadframe.

The oscillation amplitude of the capillary tip has been identified as one of the critical parameters necessary to achieve consistent bonding results. Due to the very small size of the capillary tip and the complex vibration pattern, it is difficult to accurately measure the vibration amplitude of the capillary tip in both free (unloaded) vibration mode and loaded vibration mode. A further complication is that different capillaries used in different transducers have different vibration patterns. A large number of

attempts have been made in recent years to develop systems to measure the oscillation amplitude accurately.

However, these systems either can not perform real-time measurement or involve a complex series of operations in a controlled environment. With some of the systems it is even necessary to switch off the wire bonder during the measurement process.

For example, US Patent No. 5,199,630 measures the transducer's vibration amplitude by using an opto-electronic receiver and a corresponding electronic controller. To perform the measurement, the apparatus must be re-calibrated every time and thus cannot perform real-time measurement. To measure the transducer's vibration, the apparatus must be fixed to the bonding area of the wire bonder. The apparatus needs to be removed from the bonder after measurement for normal operation of the wire bonder. Hence, the apparatus can not be used to measure the oscillation amplitude during an actual wire bonding operation. Therefore, this apparatus is not practical to conduct frequent amplitude measurements.

This apparatus is also sensitive to the ambient temperature during the measurement process as it measures only the optical power variation due to the vibration of the transducer. Therefore, this apparatus is not convenient to use in an industrial environment where the temperatures in the vicinity of the capillary tip can be high due to the bonding operation.

Furthermore, the apparatus disclosed in US 5,199,630 measures the oscillation amplitude of the ultrasonic transducer that holds the capillary tip, not the vibration amplitude of the actual capillary tip. When one capillary is replaced with a new capillary, for example due to wear of the capillary or a different capillary is needed to bond a new device, the actual vibration of the capillary may be different.

Therefore, the measurement of the oscillation amplitude of the transducer cannot be used to precisely monitor the quality of the bond, as the oscillation amplitude measured does not accurately reflect the oscillation amplitude of the capillary tip.

In accordance with a first aspect of the present invention, apparatus for detecting the oscillation amplitude of an oscillating object comprises an optical radiation source; a detector comprising first and second optical radiation sensing areas adjacent each other, the detector and the optical radiation source adapted to be located opposite each other with the oscillating object located between the source and the detector so that the object blocks a portion of the sensing areas from receiving optical radiation from the source; and a processor coupled to the detector to receive first and second output signals representing the magnitude of optical radiation sensed by the first and second optical radiation sensing areas, respectively; the processor processing the first and second output signals to obtain an indication of the amplitude of oscillation of the object.

In accordance with a second aspect of the present invention, a method of detecting the oscillation amplitude of an oscillating object comprises positioning an optical

radiation source and an optical radiation detector on opposite sides of the object, the detector comprising first and second optical radiation sensing areas; illuminating the object with optical radiation from the source and processing first and second output signals from the first and the second optical radiation sensing areas to determine the oscillation amplitude of the object.

The term "optical radiation" as used herein covers electromagnetic radiation in the visible, ultraviolet and infrared regions of the electromagnetic spectrum.

An advantage of the invention is that it permits the amplitude of oscillation of a capillary tip of an ultrasonic bonder to be measured without influencing the vibration of the capillary tip. This enables real-time measurement of the vibration amplitude of the capillary tip of a wire bonder and enables the transducer to be calibrated to produce consistent vibration amplitude of the capillary tip and to thereby improve the bond quality.

Preferably, the oscillating object is a tip of an ultrasonic transducer in an ultrasonic welding machine. Typically, where the ultrasonic welding machine is a wire bonder, the tip is a capillary tip.

Typically, the processor may generate an output oscillation signal, which can be applied to the oscillating object to modify the oscillation amplitude of the object in response to the oscillation amplitude detected by the processor. This has the advantage that as well as measuring the oscillation amplitude, the apparatus may

also control the oscillation amplitude in response to the measured oscillation amplitude.

Preferably, the output oscillation signal is input to a control device that controls oscillation of the object. Typically, where the oscillating object is a tip of an ultrasonic transducer, the control device comprises an ultrasonic wave controller.

Typically, the control device compares the oscillation amplitude with a reference oscillation amplitude and controls the oscillation of the object so that the object oscillates at substantially the reference oscillation amplitude. Preferably, the control device controls the oscillation amplitude in real time.

Typically, the optical radiation source comprises a collimating device to collimate the optical radiation exiting the source.

Preferably, the width of each of the first and second optical radiation sensing areas is greater than the sum of half the width of the oscillating object and the amplitude of oscillation of the object. Typically, the amplitude of oscillation is less than the width of the oscillating object.

In one example of the invention, the first and second optical radiation sensing areas are directed towards the optical radiation source. Typically, the first and second optical radiation sensing areas are adjacent each other. The optical radiation

sensing areas may be coplanar. Typically, the spacing between the first and second radiation sensing areas is not greater than 10% of the width of the oscillating object. Preferably, the spacing is less than 10% and is kept to minimum.

In an alternative example of the invention, the first and second optical radiation sensing areas are not directed towards the optical radiation source and the detector further comprises an optical device to direct the optical radiation onto the first and second sensing areas.

Preferably, the processor generates an indication of the oscillation amplitude by comparing the sum of the first and second output signals with the difference between the first and second output signals.

Typically, the first and second optical radiation sensing areas each comprise a photodiode.

An example of apparatus for measuring the oscillation amplitude of an oscillating object in accordance with the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of an ultrasonic transducer and an optical radiation source and detector;

Figure 2 is a schematic view of the transducer of Figure 1 and oscillation measuring apparatus incorporating the source and detector shown in Figure 1;

Figure 3 is a block diagram of the apparatus shown in Figure 2 with a measurement process unit shown in more detail;

Figure 4 is a front view of the detector shown in Figure 1;

Figure 5 is a cross-sectional view of the detector of Figure 4 in use;

Figure 6 is a cross-sectional view of another example of a detector in use;

Figures 7A, 7B and 7C are schematic diagrams showing a capillary bonding tip in a central position, a left hand position and a right side position, respectively, with respect to the detector shown in Figure 4;

Figure 8 is a graph of the output signal from the detector of Figure 4 versus capillary tip position in the Y direction;

Figure 9 is a graph of the output signal from the detector of Figure 4 versus capillary tip position in the Z direction; and

Figure 10 shows a vibration profile of a capillary in free vibration; and

Figure 11 shows a vibration profile of a capillary during wire bonding.

Figure 1 shows an ultrasonic transducer 1 having a capillary 2 with a tip 3. In Figure 1 the capillary 2 is shown in a larger scale relative to the transducer 1 for clarity and to show the shape of the capillary 2. The capillary 2 is located within a hole 4 in the end of the transducer 1 so that the longitudinal axis of the capillary 2 is at approximately right angles to the longitudinal axis of the transducer 1. The capillary 2 is removably inserted into the hole 4 and held in the hole 4, for example by means of a locking screw (not shown).

The transducer 1 and capillary 2 form part of a bond head of a wire bonder for bonding conductive wire to semiconductor dies and leadframes. The wire to be bonded passes through a through bore 5 in the capillary 2, which is coincident with the longitudinal axis 6, and extends out of the tip 3. Figure 1 also shows a sensor head 7 comprising a body 8 on which is mounted an optical radiation emitter 9 and an optical radiation detector 10.

Also shown in Figure 1, for reference purposes only, is a set of X-Y-Z co-ordinates 11. In use, during wire bonding (i.e. during ultrasonic welding of wire at the capillary tip 3 to a semiconductor die or a leadframe) the transducer 1 oscillates (or vibrates) in the Y direction with respect to the sensing head 7. This vibration has been identified as being the most important vibration contribution to the bond quality. In addition, the transducer 1 and capillary 2 may be moved up and down in the Z direction, with respect to the sensing head 7, to bring the tip 3 into contact with the surface to which the wire is to be bonded.

Figure 2 shows oscillation measurement apparatus 12 including the sensor head 7 (shown in phantom) with the transducer 1 and capillary 2. The orientation of the sensing head 7 is as viewed in the Y direction shown in Figure 1. Although in Figure 2 the transducer 1 is shown with its longitudinal axis extending in the X direction, this is for the purposes of clarity only and the longitudinal axis of the transducer would extend in the Y direction in use, as shown in Figure 1. As shown in Figure 2, the emitter 9 comprises an optical radiation source 13 and collimating optics 14. Hence, the emitter 9 generates a collimated beam 15 of optical radiation.

The detector 10 generates a first output signal V_A and a second output signal V_B which are fed to a measurement process unit 18. The measurement process unit 18 is coupled to a system controller 19 which in turn is coupled to an ultrasonic wave generator 20. The ultrasonic wave controller 20 generates an output 21 that is fed to the bond head 22 to control the amplitude of oscillation of the transducer 1 and thereby control the oscillation amplitude of the tip 3.

Figure 3 shows the detector 10 and the unit 18 in more detail. In this figure, the sensing head 7 is as viewed in the Z direction of Figure 1. The detector 10 comprises an optical aperture 23 and two photodiodes 24A, 24B located behind the optical aperture 23. Figure 5 shows a more detailed cross-sectional view of the detector 10 and capillary tip 3. The photodiodes 24 are mounted on a support 26. The photodiodes 24A, 24B generate the first and second output signals V_A, V_B respectively. The output signals V_A, V_B are in the form of voltage signals whose magnitude is indicative of the magnitude of optical radiation detected by the respective photodiode 24.

The unit 18 includes two amplifiers 35. Each amplifier 35 receives one of the output signals V_A, V_B , amplifies the signal and outputs the respective amplified signal VA, VB to a summing device 26 and a subtraction device 27. The summing device 26 sums the signals VA, VB and outputs the sum V_{AB} (=VA + VB) to the system controller 19 and to a difference device 28. The subtraction device 27 subtracts the signals VA, VB and outputs a signal S_{AB} (which is equal to the magnitude of the

subtracted signals) to the difference device 28. The difference device 28 generates an output signal V'. This is defined as follows:

$$V' = \frac{S_{AB}}{V_{AB}} = \frac{V_A - V_B}{V_A + V_B}$$

The output signal V' is output to a bandpass filter 29 and a lowpass filter 30. The signals V_A, V_B from the photodiodes 24A, 24B typically comprise a DC component and an AC component. Hence, the output V' of the difference device 28 also includes AC and DC components. Therefore, V' can be separated into a DC component V_{DAB} and an AC component V_{AC}. That is $V' = V_{DAB} + V_{AC}$.

The lowpass filter 30 removes the AC component and so outputs the DC component V_{DAB} to the system controller 19. V_{DAB} is used to position the capillary tip 3 in the Y direction and to calibrate the system during assembly.

The bandpass filter 29 removes the DC component and so outputs the AC component V_{AC} to an RMS device 31 which converts the AC component V_{AC} to a DC signal V_{AAB} which is proportional to the amplitude of the AC component V_{AC}.

In general, the output current of the photodiodes 24 is proportional to the received power of the optical radiation. This is proportional to the effective sensing area, assuming uniform optical radiation intensity I_O over the whole of the effective sensing area. The output current is converted to a proportional voltage signal V. For the system described herein and shown in the drawings, V_A and V_B are proportional to the total sensing area of the detectors 24A, 24B respectively. During measurement,

the total effective sensing area stays constant. Therefore, V_{AB} is proportional to the optical radiation intensity I_O.

V_{AB} is also used as a reference signal to correctly position the capillary tip 3 with respect to the photodiodes 24A, 24B, as described below.

The system controller 19 receives the output signals from the process unit 18. Based on the parameters set in the system controller 19 and the signals received from the process unit 18, the system controller 19 calculates the necessary control parameters to drive the ultrasonic wave controller 20. In response to the control parameters received from the system controller 19, the ultrasonic wave controller 20 outputs the signal 21 to control the amplitude of oscillation of the capillary tip 3 by controlling the oscillation of the ultrasonic transducer 1.

To measure the oscillation amplitude of the capillary tip 3, the capillary tip 3 is positioned between the emitter 9 and the detector 10, as shown in Figures 1 to 3. The collimated light beam 15 illuminates the capillary tip 3 and projects a shadow of the capillary tip 3 onto the detector 10. As shown in Figure 4, the photodiodes 24A, 24B each have a net effective or active sensing area 25A, 25B. The sensing areas 25 face towards the emitter 9 so that collimated light 15 entering the aperture 23 is detected by the sensing areas 25. The aperture 23 is large enough so that the shadow image of the capillary tip 3 (see Figures 7A, 7B and 7C) is positioned within the aperture 23 during measurement but small enough to maintain high resolution. The collimated light beam 15 must be large enough so that part of the collimated light

beam 15 passing through the aperture 23 projects an even illumination covering the combined width W of the sensing areas 25 of the photodiodes 24 and the height H of the sensing areas 25 of the photodiodes 24, as shown in Figure 4. The width W and height H, together with the separation δW of the sensing areas 25, determine the sensitivity and measuring range of the apparatus 12. The two photodiodes 24 are placed very closely behind the aperture 23. The separation δW of the sensing areas 25 is typically of the order of 10µm to 100µm. The output signals V_A and V_B are proportional to the total optical power detected by the respective photodiode 24A, 24B, and therefore, the proportion of the light beam 15 incident on the respective sensing area 25A, 25B.

The output voltage V_{AB} generated by the summing device 26 is used as a reference signal to position the capillary in the sensor head 7. Before the capillary tip 3 is positioned in the sensor head 7, the voltage V_{AB} is equal to U'_{SUM}. A pre-defined constant β is used to determine if the capillary tip 3 is correctly aligned in the sensor head 7. When the capillary tip 3 is aligned correctly, the voltage V_{AB} is equal to $U_{SUM}=\beta U'_{SUM}$ where β is a pre-defined value ranging from 0.5 to 0.8 and is dependent on the expected sensitivity and measurement range of the apparatus 12. In this way, the measurement can be made at the same section of the capillary tip 3 for the same type of capillaries.

To align the tip 3 for the Y direction, firstly the voltage V_{AB} is measured without the tip 3 in the sensor head 7. The tip 3 is then moved into the sensor head 7, and V_{AB} is monitored by the system controller 19. When the V_{AB} starts to fall which corresponds

to position Y1 in Figure 8, the capillary tip 3 is then inserted a further distance of W/2. The position of the capillary tip can be fine adjusted by using the voltage signal V_{DAB}. When the capillary tip is positioned correctly in the centre of the sensing areas, V_{DAB} will be equal to zero or will be at a minimum value. The system controller 19 records this Y position for reference as Y_{CENTRE}.

To align the tip 3 in the Z direction, firstly the voltage V_{AB} is measured without the tip 3 in the sensor head 7. This is indicated as position Z1 in Figure 9. The tip 3 is then lowered into the head 7 along the Z direction towards the centre of the sensing areas 25 according to the Y reference position Y_{CENTRE} while continuously monitoring the value of V_{AB}. The capillary tip 3 is in the correct Z position when V_{AB} is equal to U_{SUM} where $U_{SUM}=\beta U'_{SUM}$. The correct Z position is shown as position Z2 in Figure 9, where it can be seen that the tip 3 partially covers the sensing areas 25A, 25B.

The Y and Z direction alignment can be done manually or automatically. Preferably, it is performed automatically by the system controller 19 and bond header according to the parameters.

The oscillation of the capillary tip 3 is controlled by the system controller 19 via the ultrasonic wave controller 20 which drives the oscillation of the transducer 1 in response to signals received from the system controller 19. When the capillary tip 3 oscillates in the Y direction, the shadow of the tip 3 on the sensing areas 25 also moves, as shown in Figures 7A to 7C. In Figures 7A to 7C, the tip 3 has an oscillation amplitude of δY and the point of the tip 3 has an angle of 2α.

Hence, the light power detected by each photodiode changes during an oscillation cycle of the tip 3 and the corresponding output signal V_A, V_B changes accordingly. However, the output V_{AB} from the summing device 26 will remain constant.

The output signals V_A, V_B are fed to the processing unit 18 where they are amplified by the respective amplifiers 35. The signals V_A, V_B are processed as described above in the processing unit 18 to obtain the three output signals V_{AB}, V_{DAB}, V_{AAB}.

V_{DAB} indicated if the capillary tip was positioned in the centre of window of sensor' receiver. V_{AAB} is directly proportional to the vibration amplitude δY of capillary tip according to following equation:

$$\delta Y=\gamma_{AC}V_{AAB}$$

where γ_{AC} is the sensitivity of the apparatus 12. The value of γ_{AC} is calculated according to the following equation:

$$\gamma_{AC}=\beta(W-\delta W)/2M$$

where M is a constant of the processing unit 18. M is determined by the amplification of the processing unit 18. β is the pre-defined constant referred to above and is equal to U_{SUM}/U'_{SUM}. Therefore, the sensitivity of the apparatus 12 is dependent only on the width W and the separation δW, as M and β are both constants.

An alternative example of a detector 40 is shown in Figure 6. In this example the detector 40 includes two photodiodes 24A, 24B which face each other. The light

beam 15 is reflected onto the photodiodes by a reflecting device 41 mounted on a support 42. Hence, actual detection and operation of the detector 40 is identical to that for the detector 10 except that the separation δW is nearly equal to zero.

By means of the feedback system obtained by coupling the processing unit 18 to the system controller 19, it is possible to adjust the oscillation amplitude of the capillary tip 3, in real time, until the amplitude is at a desired value. In addition, due to the compact nature of the sensor head 7 it is possible to measure the oscillation amplitude of the tip 3 at any time during operation of the wire bonder, including during an actual wire bond operation. This is important as the oscillation (or vibration) profile of the tip 3 is different depending on whether the tip 3 is in free vibration (i.e. not contacting a bonding surface) or performing a wire bond operation, as shown in Figures 10 and 11, respectively. Therefore, this enables optimisation of the oscillation amplitude and a more consistent bonding process with a reduction in the number of faulty bonds.

Other advantages of the invention are that it mitigates the effect of temperature fluctuations and does not require re-calibration before each measurement. In addition, as the measurement process can be performed during the wire bond operation it is not necessary to stop or switch off the bonder to perform the measurement. This reduces the downtime of the wire bonder.

Claims

1. Apparatus for detecting the oscillation amplitude of an oscillating object, the apparatus comprising an optical radiation source; a detector comprising first and second optical radiation sensing areas adjacent each other, the detector and the optical radiation source adapted to be located opposite each other with the oscillating object located between the source and the detector so that the object blocks a portion of the sensing areas from receiving optical radiation from the source; and a processor coupled to the detector to receive first and second output signals representing the magnitude of optical radiation sensed by the first and second optical radiation sensing areas, respectively; the processor processing the first and second output signals to obtain an indication of the amplitude of oscillation of the object.

2. Apparatus according to claim 1, wherein the processor generates an output oscillation signal that is applied to the oscillating object to modify the oscillation amplitude of the object in response to the oscillation amplitude indicated by the processor.

3. Apparatus according to claim 2, wherein the output oscillation signal is input to a control device that controls oscillation of the object.

4. Apparatus according to claim 3, wherein the control device compares the oscillation amplitude with a reference value and controls the oscillation of the object so that the object oscillates at an amplitude substantially equal to the reference value.

5. Apparatus according to claim 3 or claim 4, wherein the oscillation amplitude is controlled in real time.

6. Apparatus according to any of claims 1 to 5, wherein the width of each of the first and second optical radiation sensing areas is greater than the sum of half the width of the oscillating object and the amplitude of oscillation of the object.

7. Apparatus according to any of the preceding claims, wherein the first and second optical radiation sensing areas are directed towards the optical radiation source.

8. Apparatus according to any of claims 1 to 6, wherein the first and second optical radiation sensing areas are not directed towards the optical radiation source and the detector further comprises an optical device to direct the optical radiation onto the first and second sensing areas.

9. Apparatus according to claim 7, wherein the first and second optical radiation sensing areas are adjacent each other.

10. Apparatus according to any of the preceding claims, wherein the oscillating object is a tip of an ultrasonic transducer for use in an ultrasonic welding machine.

11. A wire bonder comprising apparatus according to any of claims 1 to 9.

12. A wire bonder according to claim 11 when dependent on any of claims 3 to 5 or on any of claims 6 to 10 when dependent on any of claims 3 to 5, wherein the control device comprises an ultrasonic wave controller.

13. A method of detecting the oscillation amplitude of an oscillating object, the method comprising positioning an optical radiation source and an optical radiation detector on opposite sides of the object, the detector comprising first and second optical radiation sensing areas; illuminating the object with optical radiation from the source and processing first and second output signals from the first and the second optical radiation sensing areas to determine the oscillation amplitude of the object.

14. A method according to claim 13, wherein the first and second output signals are processed by comparing the sum of the first and second output signals with the difference between the first and second output signals.

15. A method according to claim 13 or claim 14, wherein the oscillating object is a tip of an ultrasonic transducer in an ultrasonic welding machine.

16. A method according to any of claims 13 to 15, further comprising controlling the oscillation amplitude of the oscillating object in response to the determined oscillation amplitude.

17. A method according to claim 16, wherein the oscillation amplitude is controlled by comparing the determined oscillation amplitude with a reference value and controlling the oscillation of the object to oscillate at an amplitude substantially equal to the reference value.

18. A method according to claim 16 or claim 17, wherein the oscillation amplitude is controlled in real time.

ABSTRACT

Apparatus for Detecting the Oscillation Amplitude of an Oscillating Object

Apparatus for detecting the oscillation amplitude of an oscillating object (3) includes an optical radiation source (9) and a detector (10) including first and second optical radiation sensing areas (24A, 24B) adjacent each other. The detector (10) and the optical radiation source (9) are adapted to be located opposite each other with the oscillating object (3) located between the source (9) and the detector (10) so that the object (3) blocks a portion of the sensing areas (24A, 24B) from receiving optical radiation from the source (9). A processor (18) coupled to the detector (10) receives first and second output signals representing the magnitude of optical radiation sensed by the first and second optical radiation sensing areas (24A, 24B), respectively. The processor (18) processes the first and second output signals to obtain an indication of the amplitude of oscillation of the object (3).

Figure 2

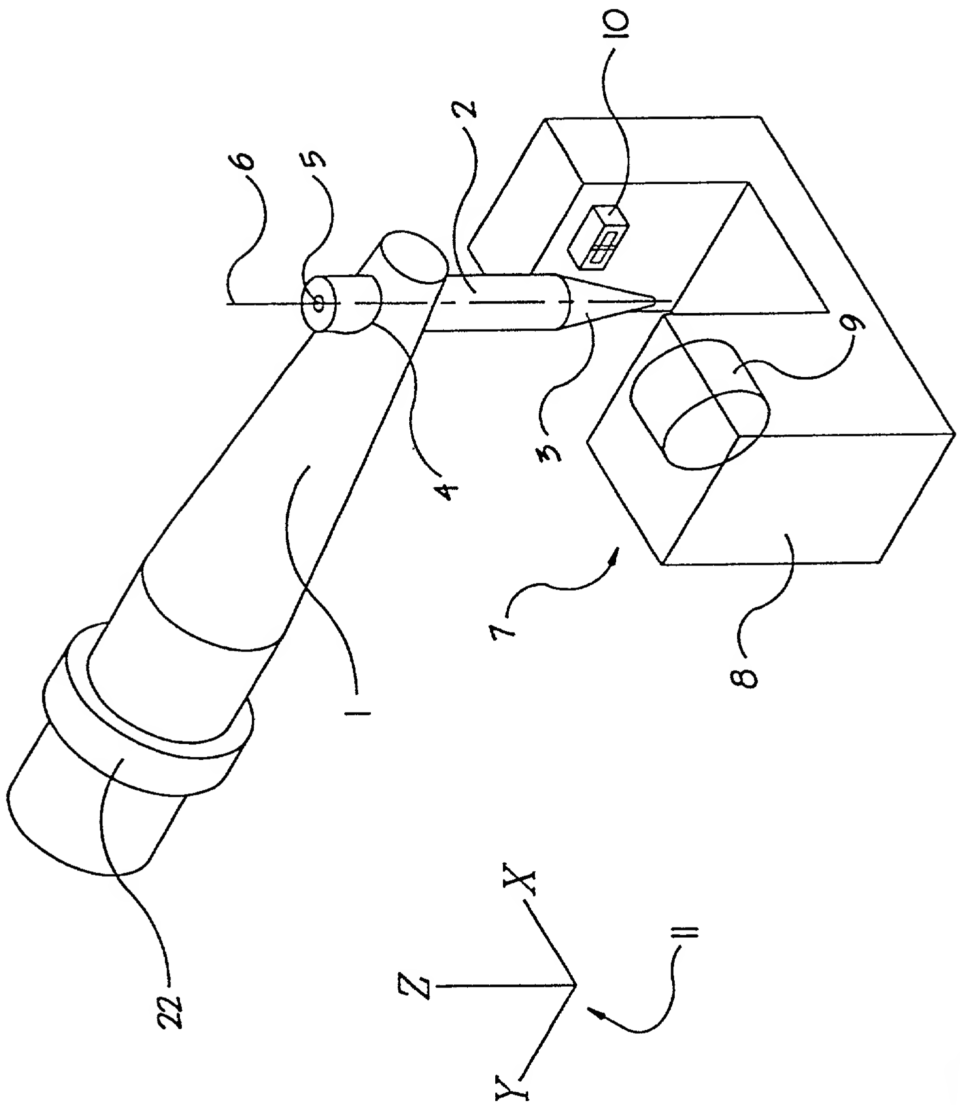


FIGURE 1

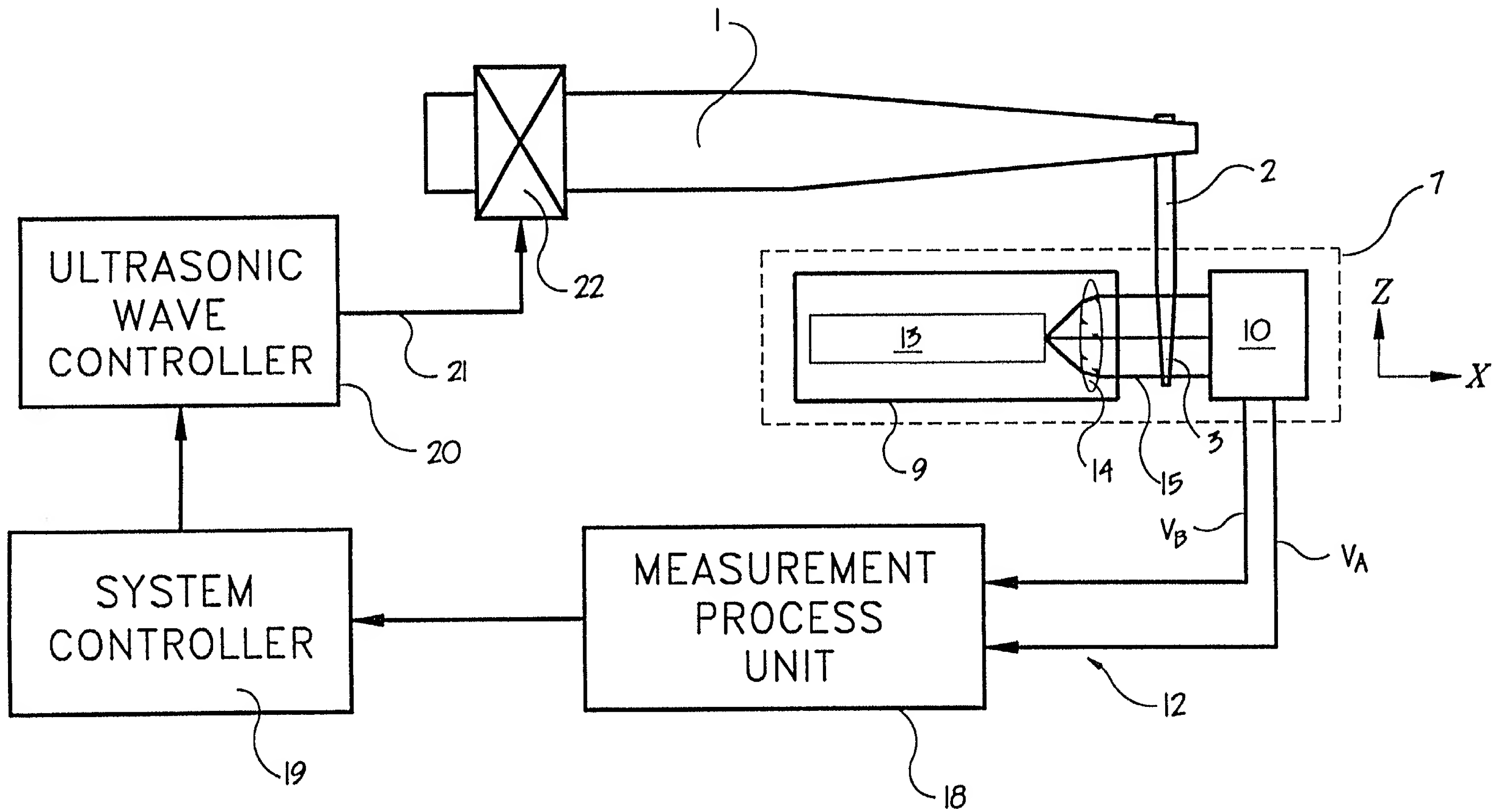
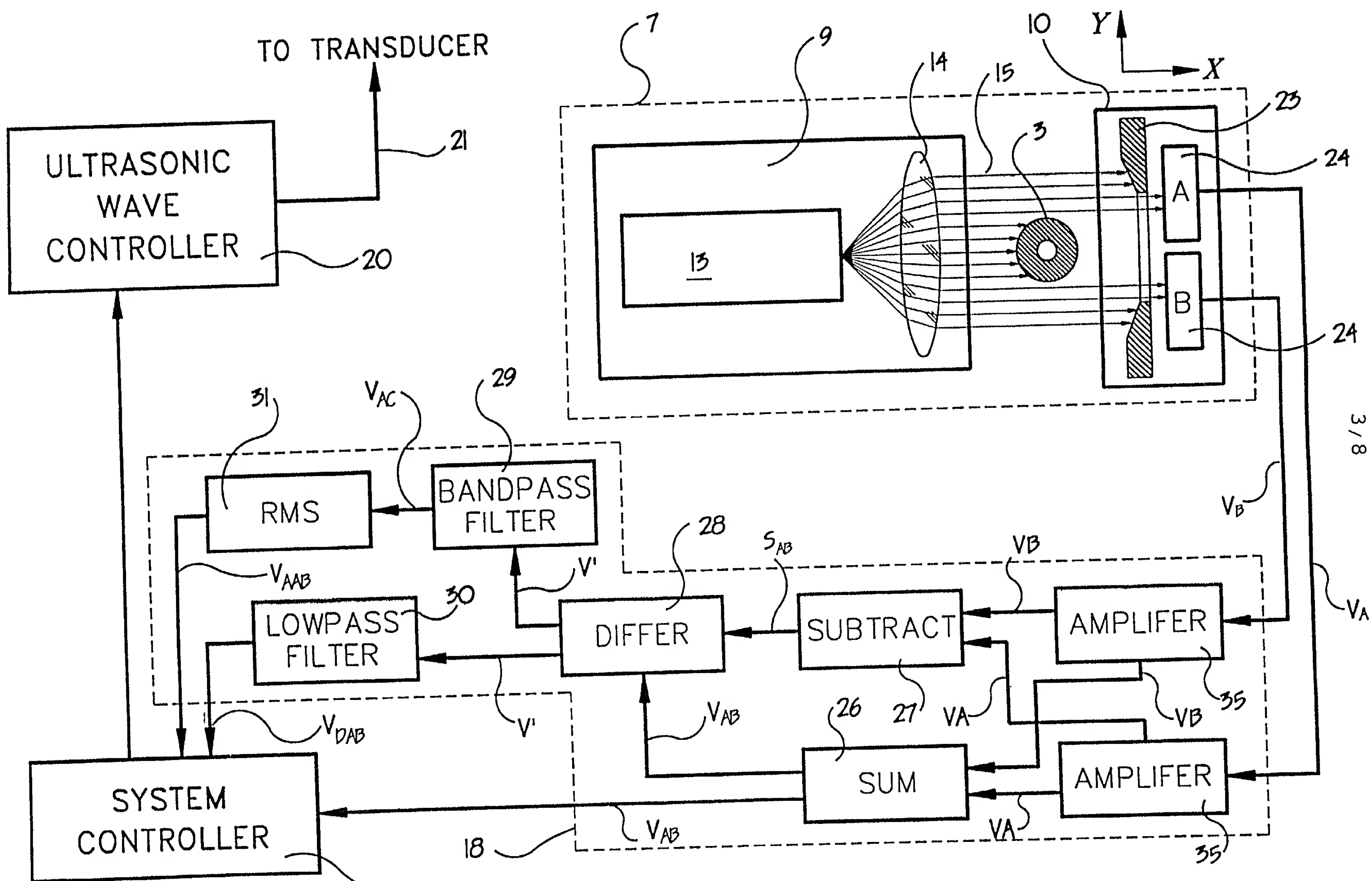

1
2
7
Z
X
10
13
ULTRASONIC WAVE CONTROLLER
22
21
20
9
14
15
3
V_B
V_A
SYSTEM CONTROLLER
MEASUREMENT PROCESS UNIT
12
19
18

FIGURE 2


TO TRANSDUCER
ULTRASONIC WAVE CONTROLLER
SYSTEM CONTROLLER
RMS
BANDPASS FILTER
LOWPASS FILTER
DIFFER
SUBTRACT
SUM
AMPLIFER
AMPLIFER
A
B
13
X
Y
V_A
V_B
V_{AB}
S_{AB}
V_{AC}
V_{AAB}
V_{DAB}
V'
7
9
10
14
15
3
23
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21
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31
35

FIGURE 3

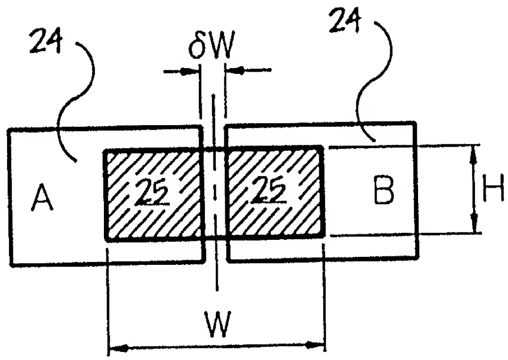


FIGURE 4

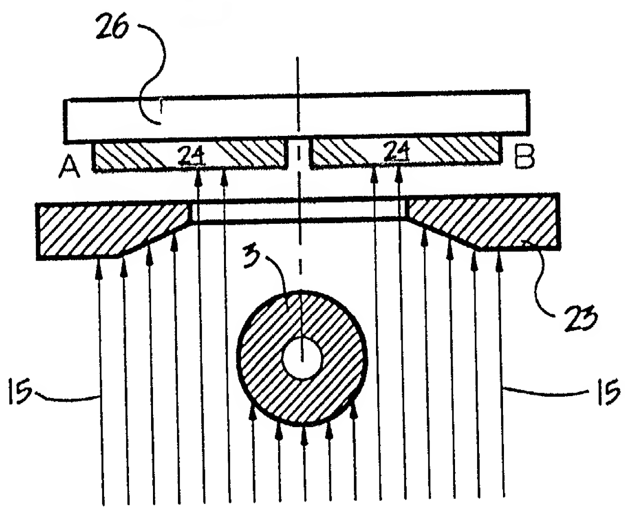


FIGURE 5

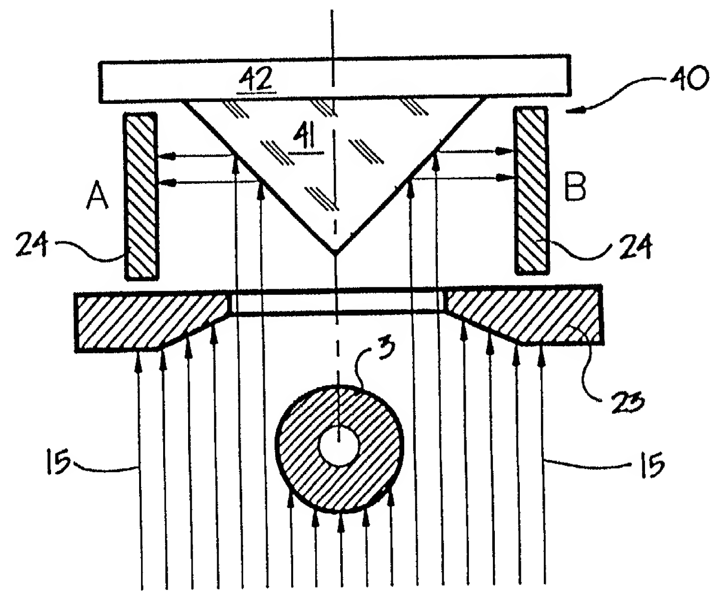


FIGURE 6

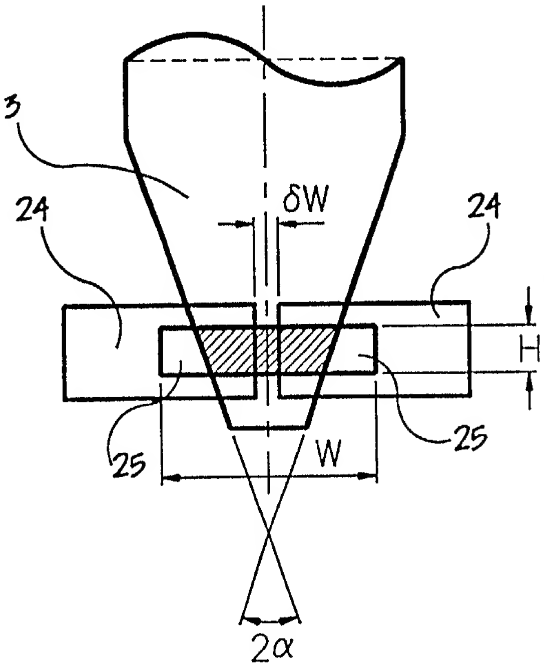


FIGURE 7A

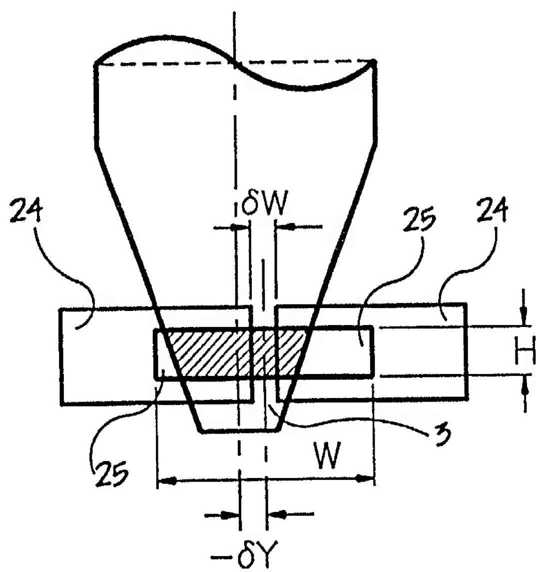


FIGURE 7B

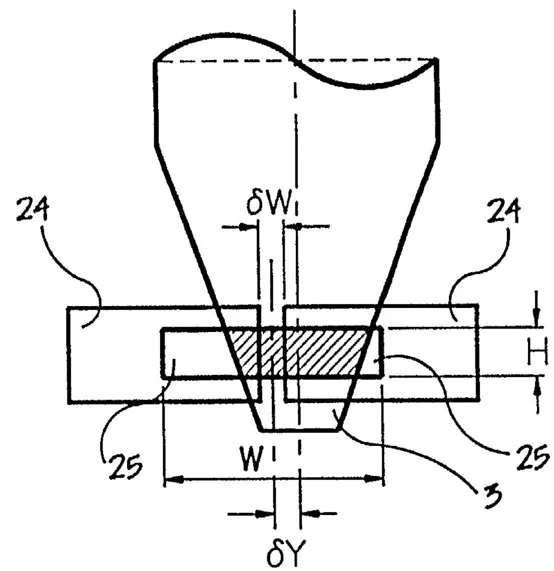


FIGURE 7C

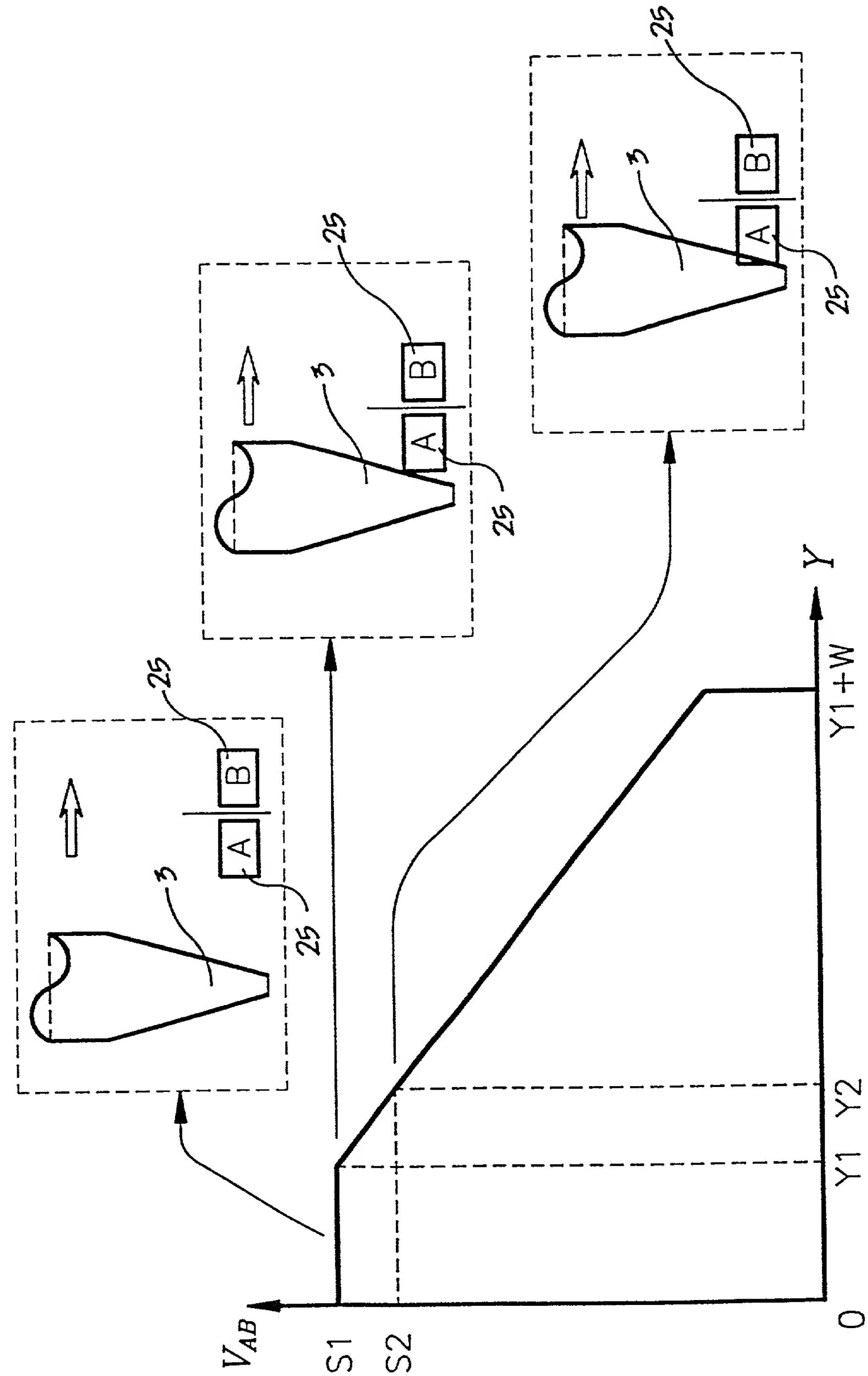


FIGURE 8

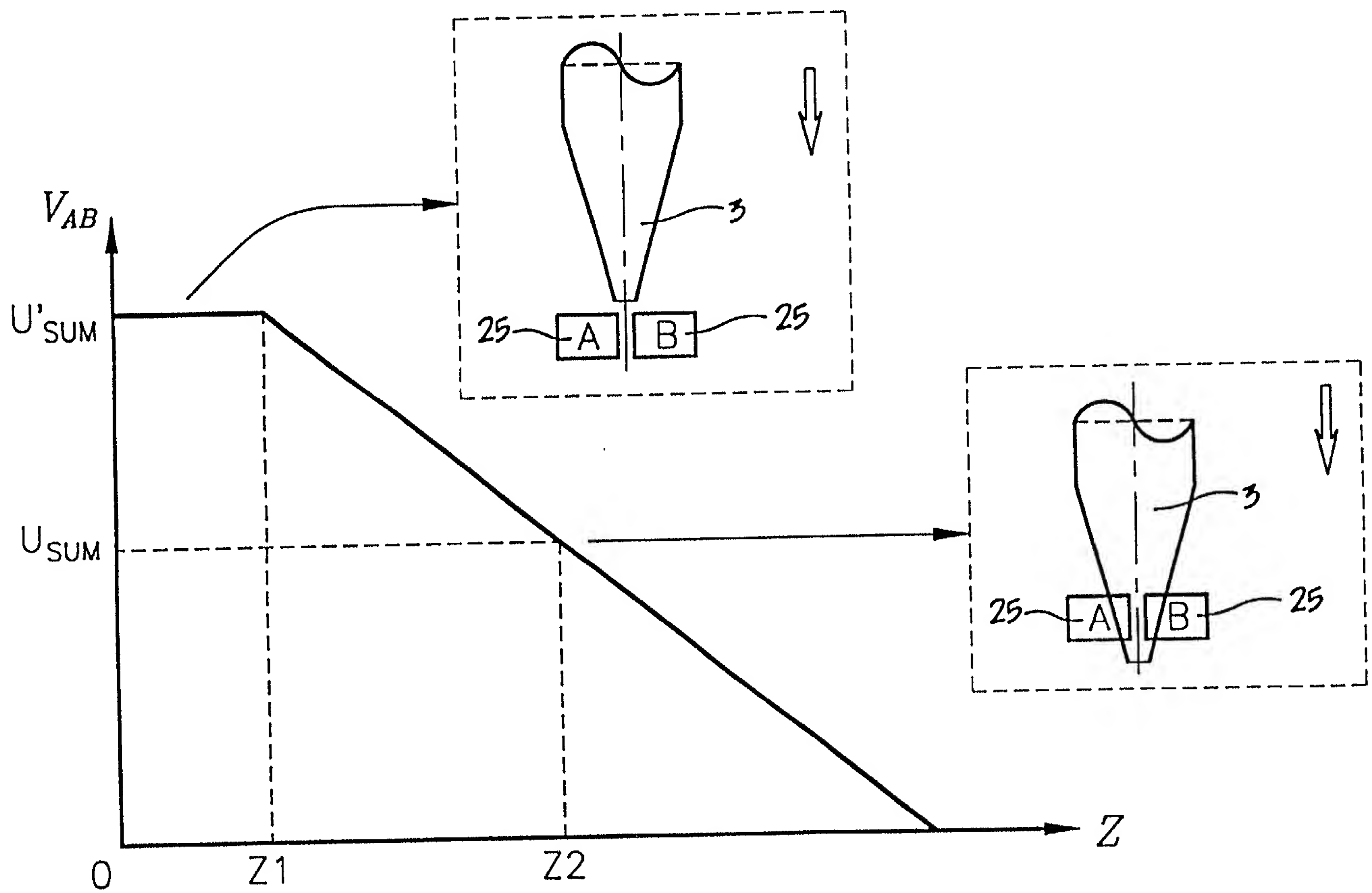
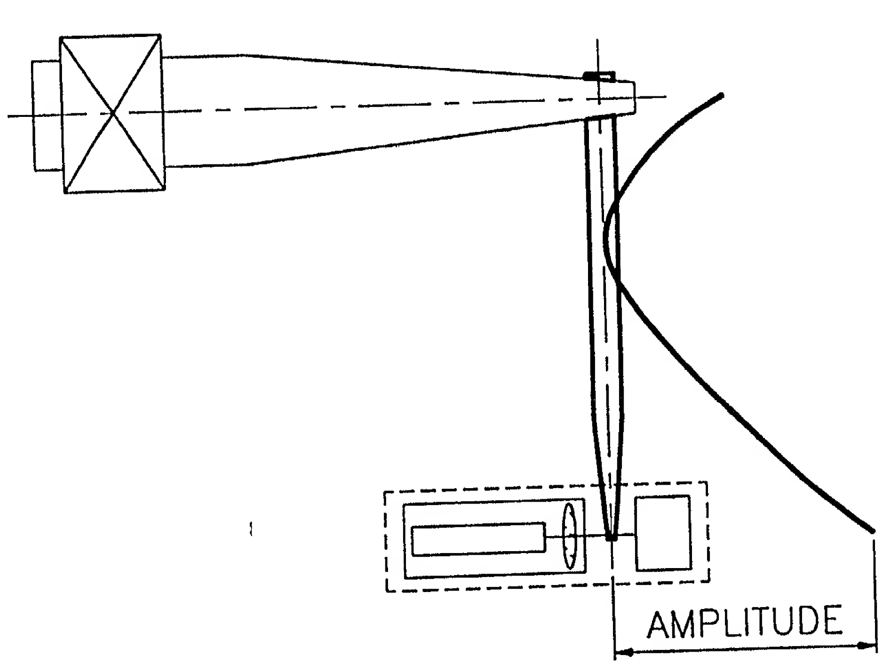
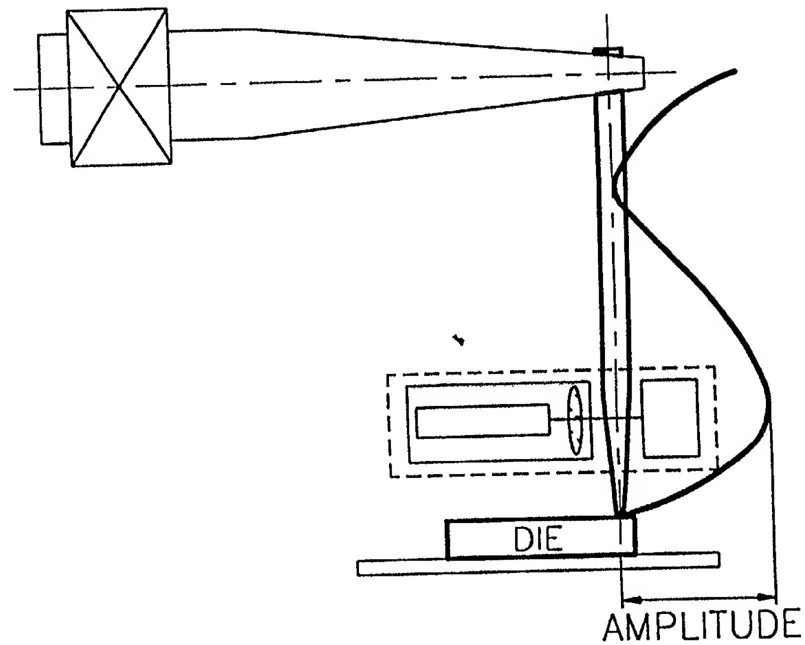


FIGURE 9



FREE VIBRATION
CALIBRATION

FIGURE 10



DURING BONDING
MEASUREMENT

FIGURE 11

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OFGS FILE NO. P/2778-12

As a below named inventor, I hereby declare that: my residence, post office address and citizenship are as stated below next to my name; that I verily believe that I am the original, first and sole inventor (if only one name is listed below) or a joint inventor (if plural inventors are named) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

APPARATUS FOR DETECTING THE OSCILLATION AMPLITUDE OF AN OSCILLATING OBJECT

the specification of which is attached hereto, unless the following box is checked:

☒ was filed on December 8, 1999 as United States patent Application Number or PCT International patent application number PCT/SG99/00139 and was amended on ______________ (if any).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose all information known to be material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim priority benefits under Title 35, United States Code §119 of any foreign application(s) for patent or inventor's certificate or United States provisional application(s) listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign or Provisional Application(s)

COUNTRY	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 U.S.C. 119
			YES ____ NO ____
			YES ____ NO ____
			YES ____ NO ____

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

UNITED STATES APPLICATION NUMBER	DATE OF FILING (day, month, year)	STATUS (patented, pending, abandoned)

I hereby appoint customer no. 2352 OSTROLENK, FABER, GERB & SOFFEN, LLP, and the members of the firm, Samuel H. Weiner - Reg. No. 18,510; Jerome M. Berliner - Reg. No. 18,653; Robert C. Faber - Reg. No. 24,322; Edward A. Meilman - Reg. No. 24,735; Steven I. Weisburd - Reg. No. 27,409; Max Moskowitz - Reg. No. 30,576; Stephen A. Soffen - Reg. No. 31,063; James A. Finder - Reg. No. 30,173; William O. Gray, III - Reg. No. 30,944; Louis C. Dujmich - Reg. No. 30,625, Douglas A. Miro - Reg. No. 31,643, and Michael J. Scheer - Reg. No. 34,425, as attorneys with full power of substitution and revocation to prosecute this application, to transact all business in the Patent & Trademark Office connected therewith and to receive all correspondence.

SEND CORRESPONDENCE TO:
OSTROLENK, FABER, GERB & SOFFEN, LLP
1180 AVENUE OF THE AMERICAS
NEW YORK, NEW YORK 10036-8403
CUSTOMER NO. 2352

DIRECT TELEPHONE CALLS TO:
(212) 382-0700

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

FULL NAME OF SOLE OR FIRST INVENTOR	INVENTOR'S SIGNATURE	DATE
Liming FAN	[signature]	June 6, 2001

RESIDENCE (City and either State or Foreign Country): Singapore 760263, Singapore
COUNTRY OF CITIZENSHIP: China
POST OFFICE ADDRESS: Blk 263 Yishun St 22 #11-177, Singapore 760263, Singapore

FULL NAME OF SECOND JOINT INVENTOR (IF ANY)	INVENTOR'S SIGNATURE	DATE
Hon Yu, Peter NG	[signature]	May 29, 2001

RESIDENCE (City and either State or Foreign Country): Singapore 589627, Singapore
COUNTRY OF CITIZENSHIP: Singapore
POST OFFICE ADDRESS: 985 Bukit Timah Road #05-09, Singapore 589627, Singapore

FULL NAME OF THIRD JOINT INVENTOR (IF ANY)	INVENTOR'S SIGNATURE	DATE
Xianbin ZHU	Zhu Xiang bin	14/06/01

RESIDENCE (City and either State or Foreign Country): Singapore 760724, Singapore
COUNTRY OF CITIZENSHIP: China
POST OFFICE ADDRESS: Blk 724 Yishun St 71 #10-181, Singapore 760724, Singapore

☒ CONTINUED ON PAGE 2

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COUNTRY	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 U.S.C. 119
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___
			YES ___ NO ___

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

FULL NAME OF FOURTH JOINT INVENTOR, IF ANY	INVENTOR'S SIGNATURE	DATE
Yam Mo WONG		28/5/2001
RESIDENCE (City and either State or Foreign Country) Singapore 787796, Singapore		COUNTRY OF CITIZENSHIP Singapore
POST OFFICE ADDRESS 255 Tagore Ave #11-02, Singapore 787796, Singapore		
FULL NAME OF FIFTH JOINT INVENTOR, IF ANY	INVENTOR'S SIGNATURE	DATE
Keng Yew SONG		25/5/2001
RESIDENCE (City and either State or Foreign Country) Singapore 550420, Singapore		COUNTRY OF CITIZENSHIP Singapore
POST OFFICE ADDRESS Blk 420 Serangoon Central #08-406, Singapore 550420, Singapore		
FULL NAME OF SIXTH JOINT INVENTOR, IF ANY	INVENTOR'S SIGNATURE	DATE
RESIDENCE (City and either State or Foreign Country)		COUNTRY OF CITIZENSHIP
POST OFFICE ADDRESS		
FULL NAME OF SEVENTH JOINT INVENTOR, IF ANY	INVENTOR'S SIGNATURE	DATE
RESIDENCE (City and either State or Foreign Country)		COUNTRY OF CITIZENSHIP
POST OFFICE ADDRESS		